PLASMA GATE SWITCH EXPERIMENT ON PEGASUS II

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The plasma gate switch is a novel technique for producing a long conduction time vacuum opening switch. The switch consists of an aluminum foil which connects the cathode to the anode in a coaxial geometry. The foil is designed so that the maximum axial acceleration is in the center of the foil and that at the appropriate time, the center opens up and magnetic flux is carried down the gun to the load region. The switch is designed to minimize the amount of mass transported into the load region. We have completed the first experimental test of this design and present results from that test. These results indicate there were some asymmetry problems in the construction of the switch but that otherwise the switch performed as expected.

Introduction

There has been much effort in the past few years to develop plasma flow switches as an opening switch for inductive store pulse power machines.[1] The motivation for this is to develop the capability of using these machines for producing radiation sources, since in general an inductive storage machine is less expensive. Because of the long time scale for the delivery of current involved in large inductive storage machines, this requires the usage of an opening switch. We have been involved with the development of these switches over the years[2], but have not been able to succeed at the level we would have wished. This led us to investigate the possibility of another type of switch which might overcome some of the problems with the plasma flow switch. A novel new design that we developed is the plasma gate switch.

There are three major problems with the plasma flow switch. One is that as the plasma flows down the coax, a boundary layer builds on the wall. This boundary layer typically is dragged with the plasma and can significantly reduce the effectiveness of the switch.[3] Another problem is caused by the large amount of plasma in the switch which is near the load at the time the switch opens. It is possible for a significant amount of this mass to be transported into the load, disrupting the load and preventing a good implosion. The third problem has to do with the background density in the power flow channel behind the switch. If this density is too high, it limits the voltage that can be developed by the switch.

The gate switch attempts to eliminate the first two of these problems. It does this by removing the effect of the wall and not allowing it to play any role in the switching. This is done by keeping the main part of the switch mass from moving down the channel, and by only letting the center region of the plasma forming the switch participate in the switching. This also reduces the amount of mass which is transported to the load region. To also reduce this mass, cylindrical bars are used for the inner and outer conductors of the transmission line through which the plasma can escape. Simulations showed this to work well and so using these simulations, we designed an experiment.

In the following section, we discuss the simulations used to design this switch. We then describe the specific aspects of this experiment and discuss our results and conclusions.

Simulations

The design of this switch is driven by the desire to have a magnetic-gate opening effect so that the opening region is away from the electrodes and not affected by boundary layers or other wall-effects. The initial thickness-profile versus radius of the switch foil is shown in figure 1. This profile coupled with the $1/r^2$ magnetic force gives an axial-acceleration profile (shown in figure 2) which is symmetric about the mean radius of the foil. The acceleration of the central portion of the foil is 3.8 times greater than the inside and outside portions. The characteristic width and depth of the thin region and the overall thickness of the foil where chosen based on fabrication concerns. (The fabrication of these foils is discussed elsewhere at this conference.)

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Figure 1. Design Thickness of the Aluminum Foil for the Plasma Gate Switch.
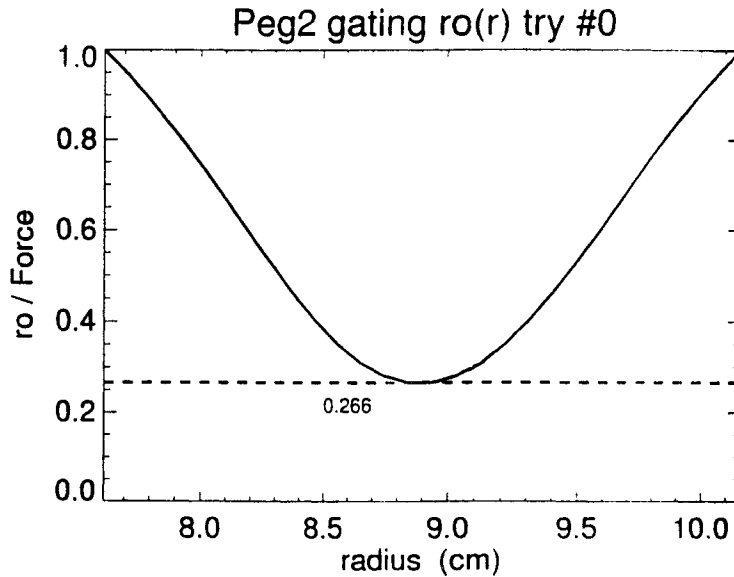
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Figure 2. Axial Acceleration of the Mass in the Plasma Gate Switch.

The ultimate plan is to have a switch-region coupled to an implosion region as shown in figure 3. For the first experimental test, the desire was to examine the switch behavior into a straight vacuum inductance region. The length of this region was chosen to have similar impedance as an actual implosion. The end of this channel is a solid conducting wall electrically connected to the inner and outer electrodes. (In the first experimental test, viewing windows where cut into this piece to allow axial viewing of the switch plasma.)
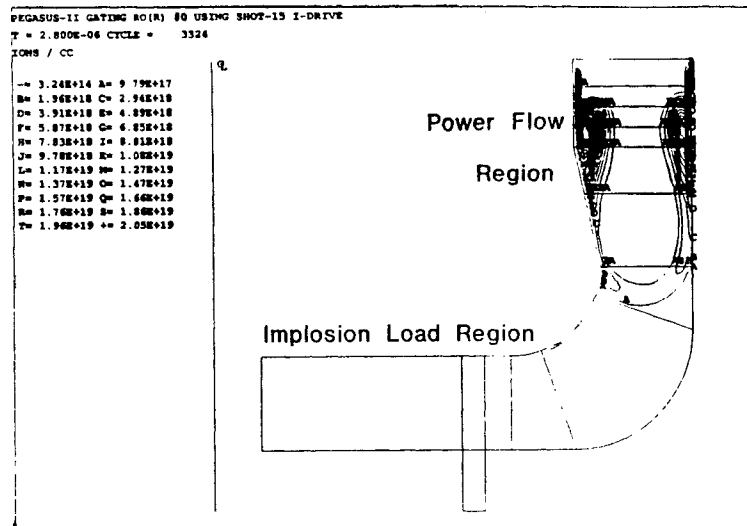
Figure 3. Ultimate Design of the Coupling of the Plasma Gate Switch to an Implosion Load.

To provide a "get-lost" mechanism for the bulk of the plasma, the inner and outer electrode walls just past the initial foil position are not solid, but consist of axially-running bars, like the typical outer electrode of a plasma-focus. There are 16 bars for the inner electrode and 24 bars for the outer electrode, and the bars are 6 cm long. Beyond the bars the electrode walls are again solid.

There is an insulating electrical break in the outer electrode 8.5 cm past the initial foil position. This prevents precursor currents from flowing in the load region past the insulating gap. The gap shorts out when the switch opens and low-density plasma from the switch crosses the gap. Both simulations and experimental data show that this gap works as expected.

Detailed two-dimensional MHD simulations were performed using the MACH2 code[4]. The simulations start 600-ns into the Pegasus-II bank-current rise, which is roughly a few hundred nanoseconds after the foil has burst and turned into plasma. The simulations start with a uniform aluminum plasma thickness of 1.26-mm, and a plasma-density radial-profile which gives the correct aerial-density profile of the initial foil. The initial plasma temperature is 1-eV, the bank-current is 1.9-MA, and the initial current-density is uniform through the thickness of the plasma (i.e. fully diffused through the aluminum). Calculations have been done with the plasma background-density set at 10^{-3}kg/m^3 and 10^{-4}kg/m^3. To approximate the regions of the walls which are comprised of bars, the boundary conditions in the simulation allow plasma to freely leave the computational region.

Contours of the plasma ion density at times near the opening-time (figure 4, note that the x-y aspect is not true in the figure) show that the thin region of the plasma becomes thinner as it moves downstream ahead of the bulk plasma, and eventually the plasma gates open at about 3μs into the bank-current rise.
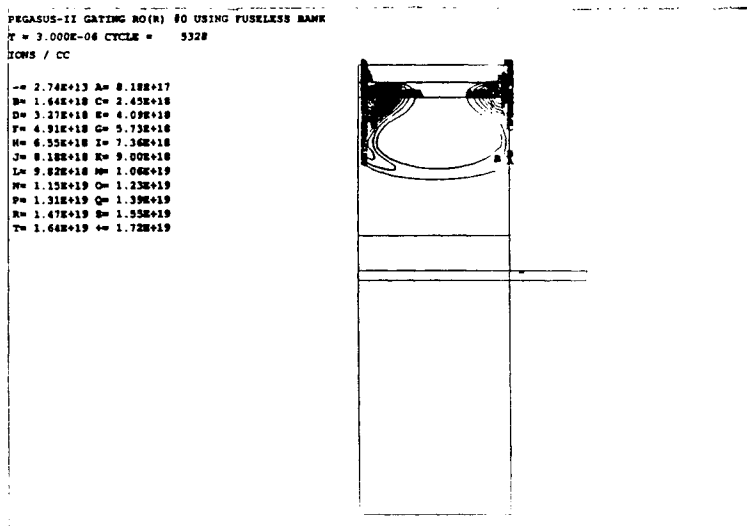

Figure 4. Density Contours of the Mass of the Plasma Gate Switch at the Time of Opening.

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Simulated B-dot probe signals are shown in figure 5. The top curve (1.9 MA at 0.6 μs) is the bank current. The probes are evenly spaced down the channel and near the outer electrode. The results for probes near the inner electrode are virtually identical. The rise of current above the bank current at the very end of the channel is due to a "generator" effect when magnetized low-density plasma hits the end-plate.
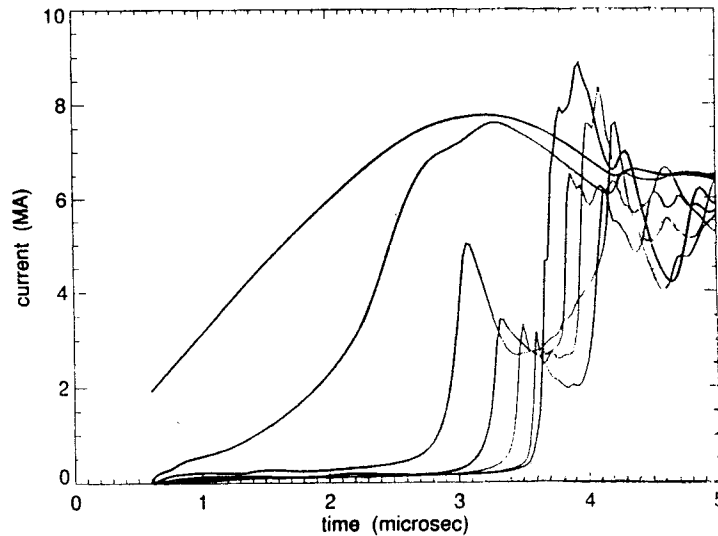

Figure 5.   Calculated Probe Signals for the Plasma Gate Switch Experiment.

Description of Experiment

Using the switch as designed above, we set up an experiment to compare to the predicted performance. This first test did not include an implosion load. We simply extended the coaxial region of the transmission line to approximate the inductance the switch would see for an implosion load. A schematic of the experimental setup is shown in figure 6. We have 9 sets of magnetic probes placed down the coax every two centimeters and one placed much above the initial position of the switch. Most of these probes were on the outer electrode, but some were also on the inner. The last probe is spaced differently, since it was right next to the end of the channel. Also, at the end of the channel the electrode was not a solid conductor, but had openings in it to view the light emission of the switch plasma. A visible framing camera was used to image the switch as a function of time. This difference was the only significant one between the experiment and the simulation.
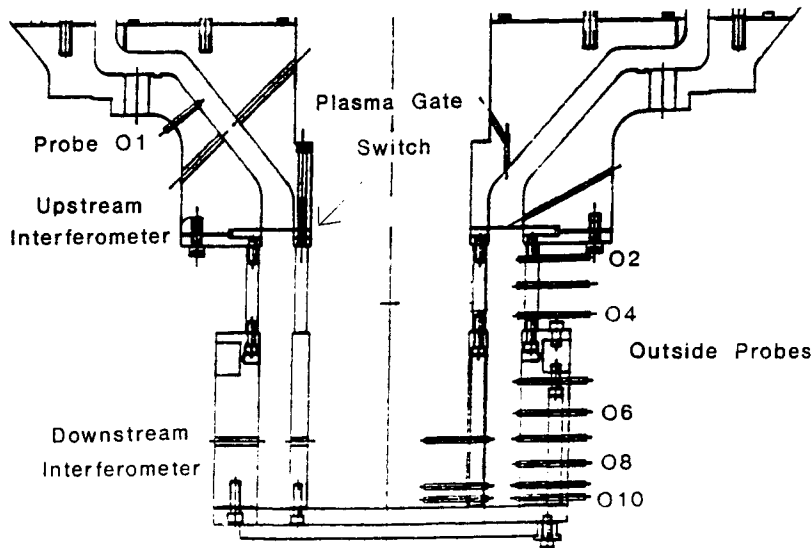

Figure 6.   Schematic Drawing of the Plasma Gate Switch Experiment.

Other diagnostics used for this experiment included two interferometers to measure the plasma density at separate axial locations, Faraday rotation sensors to measure the current, a Rogowski coil to also measure the current, and a shine through light monitor to measure the time at which the switch opened.

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Results

The results from the experiment were encouraging despite the fact that we had one significant problem with the switch. This was an asymmetry in the way the foil was mounted on the rings which hold it in place in the power flow channel. This resulted in the thinnest part of the foil, which was meant to be in the center of the channel, was offset about 8 mm, or about 1/3 the width of the power flow channel. One can see this clearly in the images taken with the visible framing camera, which are shown in figure 7.
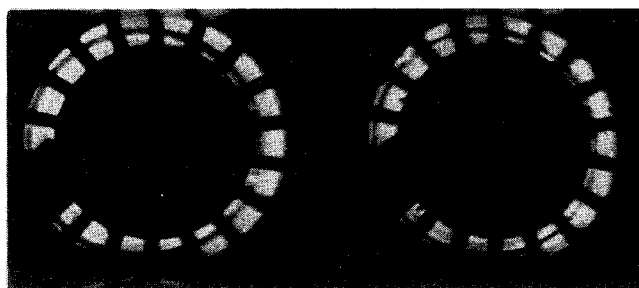

Figure 7.   Visible End on Images of the Plasma Gate Switch.

Here we see that a dark circular band appears at a time just after opening, corresponding to the thin part of the foil opening up. This dark band is about 4 mm wide and is significantly off-center. This produces an asymmetric switching event, which was seen on the current probes placed at different azimuthal positions near the switch. However, by the time the current reached the end of the channel, there was little evidence of this asymmetry. The offset did cause the switch to open early, at 2.3 microseconds into the current pulse compared to the predicted time of 3.0 microseconds.

Another factor affecting the performance of the switch is that we had a breakdown in the power flow channel behind the initial position of the switch at the time of switching. We have seen this effect on some of our other plasma flow switch shots, and we believe it is partly responsible for the high background densities which we believe we have. One can see the effect of this by comparing the current measured by the Rogowski coil, which measures the current for the entire power flow channel, with the magnetic probe O1, which is above the initial position of the switch. This is shown in figure 8.
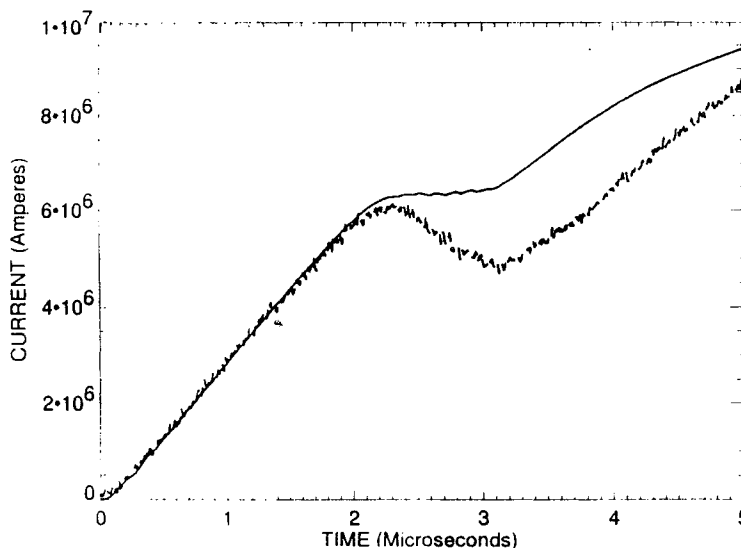

Figure 8.   Comparison of Rogowski Coil Signal with Current Measured Just Above the Switch.
(——— Rogowski, – – – O1).

When the switch opens up at 2.3 microseconds, the Rogowski signal stays level, while the current in the switch region drops. This indicates there is current being carried in the power flow channel above the switch and it also limits the amount of magnetic flux available to assist in pushing the current down the channel. Despite this fact, the current still moves down the channel rapidly and very similar to how it was predicted to perform. These current traces are shown in figure 9. In this figure we see that nearly 4 MA of the 5 MA available arrives in the

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downstream part of the power flow channel with a rise time of about 100 ns. This is in general better performance than we have had with the plasma flow switch, but there are still problems.
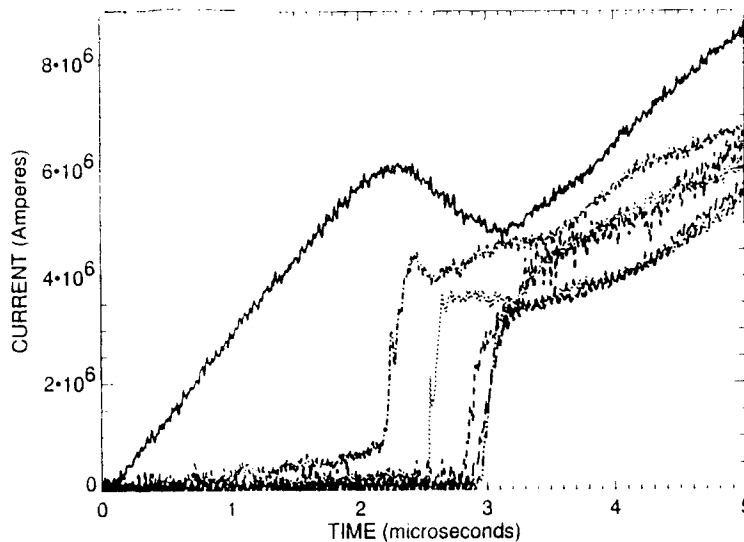

Figure 9.   Magnetic Probe Signals in the Power Flow Channel.
(— 01, – · – · 02, · · · · 04, - - - 06, – – 08, – · · · 010).

One major problem is that the current downstream does not reach the drive current. This does occur in the simulation because the plasma flow stagnates on the wall at the end of the coaxial channel. When the flow hits the wall, a shock moves up the channel, stopping the plasma flow and allowing the current to come up to full value. We believe this did not happen in the experiment for two reasons. First, because of the asymmetric way the gate foil opened up, the plasma flow down the channel was very likely not simply 1-D. Also, the electrode at the bottom was not solid but had openings in it to allow light to escape. This by itself would prevent the shock from being produced as it was in the simulation.

We also have other concerns regarding this switch. We are not sure how such a switch will work when the current must turn a corner. We have tried to address this in the design shown in figure 3 by making the corners round, but we have no data yet to say whether it will work. We also believe that the background density is a serious problem for us and that until we fix that, no switch we use will work very well. Only after solving this problem will we be able to address the other problems in a straightforward
manner.

Conclusion

We have fired one experiment testing a novel type of plasma opening switch which we have called a plasma gate switch. The results from this test are consistent with the predictions from simulations despite the fact that the switch was mounted in the machine asymmetrically and thus did not open as expected. The performance of this switch design was promising, but more work must be done to determine if this type of switch can be used for an implosion load.

References

1. P. J. Turchi, [et al.], "Review of Plasma Flow Switch Development," IEEE Transactions on Plasma Science, vol. PS-15, 747, (1987).
2. J. C. Cochrane et al., "Plasma Flow Switch and Foil Implosion Experiments on Pegasus II," Proceedings of the 9th IEEE Pulsed Power Conference, Albuquerque, NM, (1993).
3. J. C. Cochrane, et al., "Plasma Flow Switch Experiments on the Pegasus Facility," Proceedings of the 8th IEEE Pulsed Power Conference, San Diego, CA, (1991).
4. M. H. Frese, "MACH2: A two-dimensional magnetohydrodynamic simulation code for complex experimental configuration," Mission Research Corp., Albuquerque, NM, Tech. Rep. AMRC-R-874.